SIMULATION OF NETWORKED CONTROL SYSTEMS VIA TRUETIME

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Abstract

Distributed control systems have been one of the most studied and challenging areas in control. Networked Control Systems (NCSs) are one type of distributed control systems where sensors, actuators and controllers are interconnected by communication networks. Integrating computer networks into control systems to replace the traditional point-to-point wiring has enormous advantages but on the other hand NCSs bring several issues like network-induced delays or packet dropouts. We need to know the behavior and characteristics of networked control systems for designing better and robust control systems. In this paper we simulate networked control system using TrueTime. TrueTime is a Matlab/Simulink-based simulator for real-time control systems. We are focused on simulation and testing modern communication standard CAN and also wireless standard ZigBee.

1 Introduction

Nowadays we can observe the trend of passing from the traditional centralized control to distributed control systems. The vast progress in network technology over the past decade is bringing an advancing trend to control system, where point-to-point cables are replaced by communication networks. The control systems where sensors, actuators and controllers are interconnected by communication network are called Networked control systems (NCSs). There are many advantages in NCSs, such as low cost, reduced weight and power requirements, simple installation and maintenance, and high reliability. It leads to great application potential of NCSs in industry [1,2].

However, application of communication networks brings new problems into the feedback loop, such as time-varying delays and the potential loss of information, which makes the analysis and design of NCSs complicated. Many authors interested in topics of NCSs study these problems. To choose effective approach for NCSs how to accommodate the effects of network-induced delays and packet dropouts is very important to know the network characteristics. As a result of NCSs characteristics, the conventional control theories must be re-evaluated before applying to NCSs [2,3,4].

Best way how to determine network behavior is to design and using simulation model. It is helpful during the development of NCSs because they are usually very complex.

In this paper we are focused on simulation of networked control systems using TrueTime At first, we introduce the TrueTime toolbox (for Matlab) as a simple and easy way how to realize several network types. We are focused on simulation and testing communication standard CAN and also wireless standard ZigBee.

Using TrueTime we demonstrate how the different network types (CAN and ZigBee) and their basic settings and parameters can effect the control process of simple plant – DC motor. In the last section we briefly compare simulation results of motor control system for wired communication standard CAN and wireless communication standard ZigBee.

2 Networked Control Systems

The idea of remote controlled operation leads to changing of the usual design approaches to the control systems. We can talk about distributed control systems (DCSs). Networked control systems (NCSs) are spatially distributed systems for which the communication between sensors, actuators, and controllers is supported by a shared communication network [1].

As we already mentioned networks enable remote data transfers and data exchanges among users and bring a lot of benefits. The insertion of the communication network in the feedback control loop also makes the analysis and design of an NCS complex.

Because of that, many industrial companies are interested in applying networks for remote industrial control purposes and factory automation. It leads to research and several new communications media and protocols have been released. Simplify NCS block diagram we can see at figure 1.

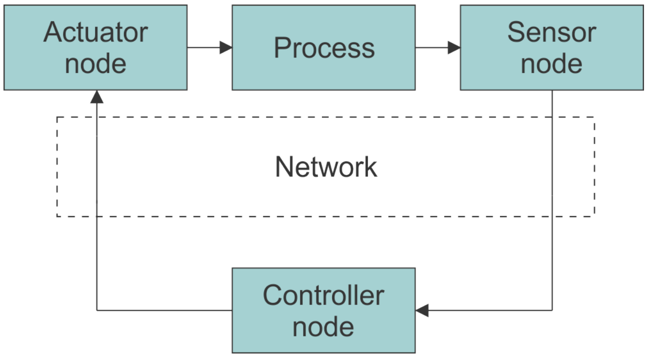

Figure 1: NCS block diagram

On the other hand integrating computer networks into control systems brings also disadvantages. Regardless of the type of network used, the networked control system (NCS) performance is always affected by network delays or packet dropouts. These two key issues are widely known to degrade the performance or robustness of a control system [1,5].

The question is how to deal with these issues? The solution cannot be obtained only by improving the communication infrastructure. It is important to take a system's perspective to overcome these problems and also develop control algorithms that can deal with communication imperfections and constraints. For this approach is very useful to use software that is able to design and simulate network control systems [6].

2.1 Commmuncation channels

The NCSs can be designed using two different types of communication network. Wired communication channels and their communication protocols are the most common, most reliable and most secure way of connecting nodes communicating over an industrial network. In last few years also the wireless communication networks have became very popular. There are several technologies for usage in industrial applications. The main differences are in the transfer rates and the communication protocols [7].

In this chapter we describe the basic features and characteristics of CAN and ZigBee communication technology which are used for NCS simulation using TrueTime.

Controller Area Network (CAN)

CAN, which is the short of Controller Area Network, is the most mature and developable bus technology. It's a serial communicational network efficiently supports distributed control and real-time control. CAN was originally developed for car industry. Because of its effectiveness CAN bus has also spread into others fields of industry.

CAN bus is reliable, fast and cost effective communication channel for multi master and real-time applications. It is ideally suites applications requiring high number of short messages for multi recipients and system-wide data consistency is mandatory in a short period of time with high reliability in rugged operating environments [8,9].

CAN standard do not include application layer protocol. Several protocols was design for different applications. In industrial applications are especially used CANopen and DeviceNet.

ZigBee

ZigBee technology has recently become one of important and significant options for Wireless Sensor Network (WSN), since it possesses many advantages such as low power consumption, low data rate, low cost and short-time delay characteristic. ZigBee is the only standards-based wireless 802.15.4 technology. ZigBee protocol features include: support for multiple network topologies such as point-to-point, point-to-multipoint and mesh networks, low duty cycle – provides long battery life, low latency, up to 65,000 nodes per network, encryption for secure data connections [10,11].

Expected applications for the ZigBee are building automation, security systems, remote control, remote meter reading and computer peripherals [12].

3 TrueTime

TrueTime is a Matlab/Simulink-based simulator for real-time control systems. TrueTime facilitates cosimulation of controller task execution in real-time kernels, network transmissions, and continuous plant dynamics. The kernel block simulates a real-time kernel executing user-defined tasks and interrupt handlers. The various network blocks allow node (kernel blocks) to communicate over simulated wired or wireless networks.

The TrueTime network block simulates medium access and packet transmission in a local area network. Six simple models of networks are supported: CSMA/CD (e.g. Ethernet), CSMA/AMP (e.g. CAN), Round Robin (e.g. Token Bus), FDMA, TDMA (e.g. TTP), and Switched Ethernet.

The usage of the wireless network block is similar to and works in the same way as the wired one. To also take the path-loss of the radio signals into account, it has x and y inputs to specify the true location of the nodes. Two network protocols are supported at this moment: IEEE 802.11b/g (WLAN) and IEEE 802.15.4 (ZigBee) [13].

The block library consists of the TrueTime Kernel block that simulates a real-time kernel executing user defined tasks and interrupt handlers, the Network block that allows nodes to communicate over simulated network, a couple of standalone interface blocks and of the Battery block that allows modeling of battery driven operation.

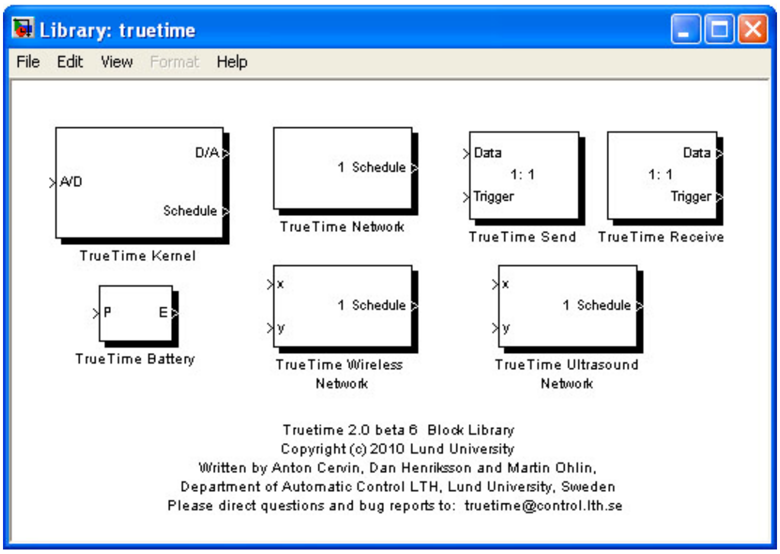

Figure 2: The TrueTime block library

4 NCSs simulations

Each of simulation schema consists of PID controller, process and wired or wireless network blocks. We used PID controller and transfer function of the process according to Tipsuwan [1]. Mathematical description of process ($G_p(s)$) and controller ($G_c(s)$) are followed:

$$Gp(s) = \frac{2029.826}{(s + 26.29)(s + 2.296)} \qquad (1)$$

$$Gc(s) = \frac{0.1701(s + 0.378/0.1701)}{s} \qquad (2)$$

For representation of our CAN and ZigBee network blocks from TrueTime were used. Basic properties of each network can be set in TrueTime Network block/ TrueTime Wireless Network block. For simulation we set mainly Network type, number of nodes, loss probability but the others can be set too. Network nodes (Controller, Actuator and Sensor) are represented by TrueTime Send and TrueTime Receive blocks which provide data exchange.

For each communication network (wired and wireless) we did three different experiments to demonstrate how sampling period, number of nodes and packet dropouts can influence performance of NCS. In this section we describe these tree issues further.

Sampling period

In networked control system sensors usually sample process values in periodic times. For most of the dynamics systems more samples lead to much better control of the system. Networked control systems needn't to have the same respond for this situation. Higher sampling period can cause NCS overload what leads to network delays and performance of control system could be degraded.

Node numbers

The aim of implementation of communication networks into control systems is to control more then one system over the same network. Creating of multiple systems can cause also network overload because there is higher expectancy that more than one node want to transmit data through the communication channel at the same time.

Packet dropouts

In wireless networks there is higher probability to lost some information. It can be caused by disturbing effects of the environment or long distance between nodes. When packet is lost retransmission of data is possible when the sampling period is not too small. Many times last received sample is used again for computation.

4.1 Simulation results for wired NCS

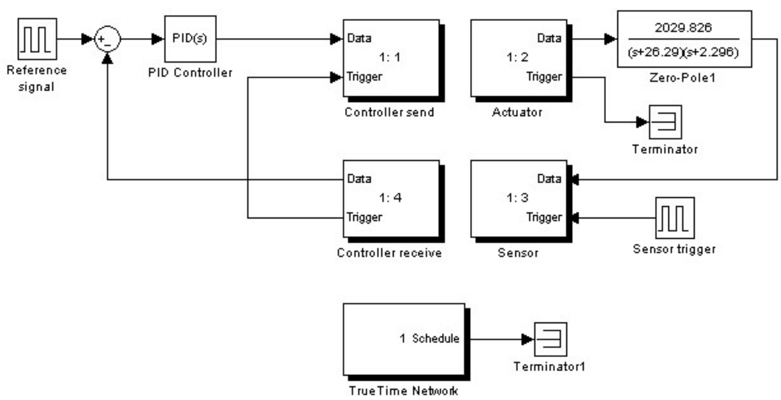

Figure 3: Wired NCS simulation model

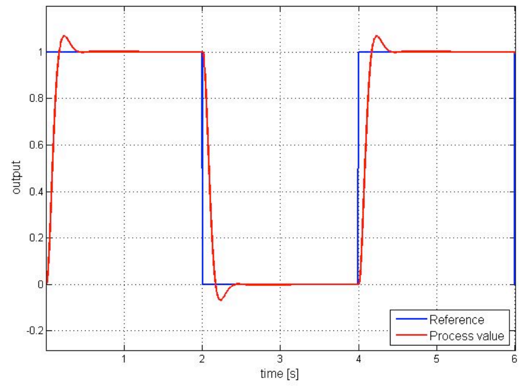

Figure 4: System with 0.005s sampling time

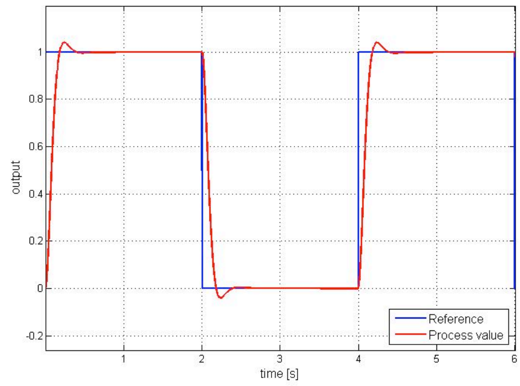

Figure 5: System with 0.002s sampling time

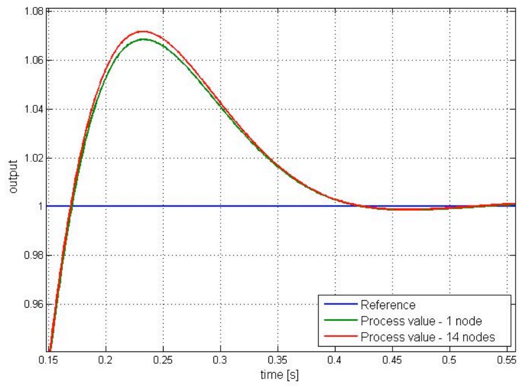

Figure 6: System with 14 nodes

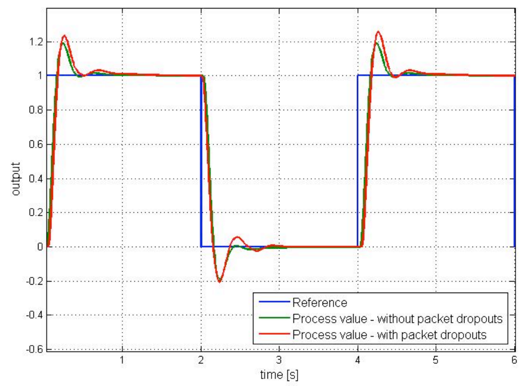

Figure 7: System with 15% packet dropouts

From the charts we can see NCS response of process value for each of ours experiments. According to response of process value on figure 4 we can consider performance of control system as good enough. All others simulations we compare against to this simulations.

In our first simulation (see figure 5) we changed sampling periods from 0.005 s to 0.002 s. We wanted to demonstrate degradation of NCS performance. However, with higher sampling period we observe better control of process value. CAN bus is really fast communication channel and there was no problem to handle the control of process with more samples. Aim of the second experiment (see figure 6) was to demonstrate what happened when more than one node want to transmit data through the communication channel at the same time. Some nodes have to wait until the network is available for transmit. It causes some delays and performance of control decrease. On figure 7 we can see how packet dropouts can also degrade NCSs because of loss some information.

4.2 Simulation results for wireless NCS

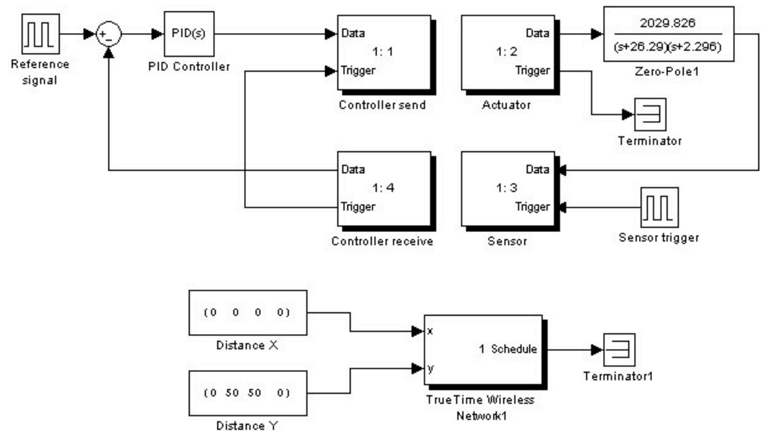

Figure 8: Wireless NCS simulation model

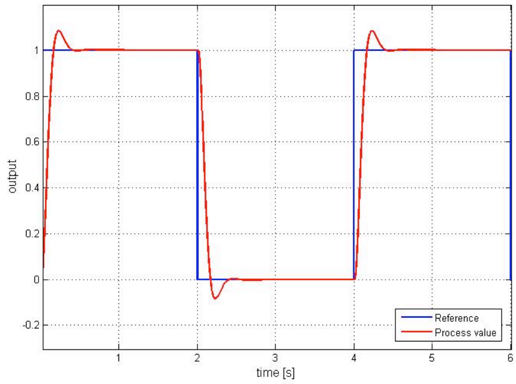

Figure 9: System with 0.005s sampling time

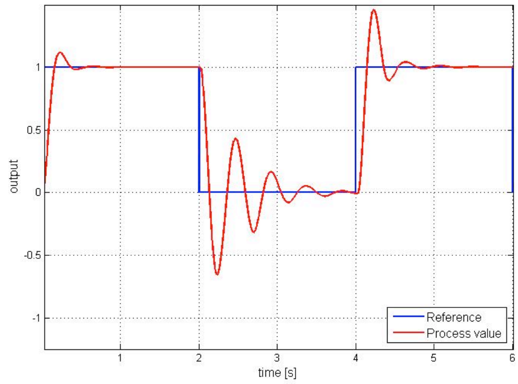

Figure 10: System with 0.00285s sampling time

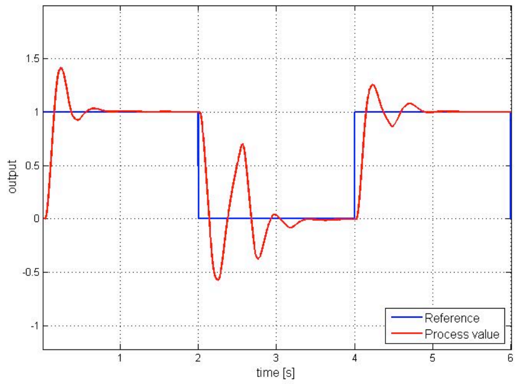

Figure 11: System with 14 nodes

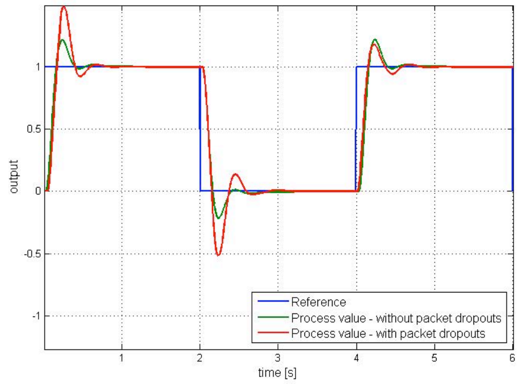

Figure 12: System with 15% packet dropouts

For wireless communication network we did the same experiments as with wired network. All simulations for wireless network we will compare against to the simulations on figure 9.

In our first simulation (see figure 10) we changed sampling periods from 0.005 s to 0.00285 s. Communication was overloaded and performance of control systems decreased. For NCS with more nodes and with packet dropouts we also observed not good quality of control. The reasons are the same as in case of wired network communication channel. Comparing wireless network to wired network we can sum up that wireless network is not as stable and robust as wired communication channel.

5 Conclusion

Recently, the progress in network technology over the past decade is bringing an advancing trend to control system, where communication networks replace point-to-point cables. This paper has introduced the fundamental characteristics of NCSs and communication network CAN and ZigBee. We also described simulator for NCSs. TrueTime simulator is very useful and Matlab/Simulink based tool.

We designed two networked control systems. The first one was designed with wired and the second one with wireless communication network. We focused on three problems of NCSs that are sampling period, network overload and packet dropout. For each of these systems we did the same experiments and proved that performance of NCSs can be effect by bringing already mentioned tree issues in.

Acknowledgments

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